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SCREW REINFORCEMENT ON BEAM-TO-COLUMN DOWEL-TYPE CONNECTION

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ABSTRACT: This study used self-tapping screws with partial threads on the point end to reinforce beam-to-column moment resisting connections. The mechanical properties of the timber-steel-timber connection were significantly improved compared to unreinforced connections. A preliminary calculation method is applied to predict the characteristic moment-resisting capacity of the unreinforced connection. The prediction is shown to be conservative. In the experiments, with a small gap in between, the two timber members in the connection started to bear on each other which shifted the centre of rotation of the connection and caused excessive tensile stresses perpendicular to the grain in the lower part of the connection. The location of the self-tapping screw regarding the design of the connections is addressed.

KEYWORDS: Moment-resisting connection, Self-tapping screws, Reinforcement, Theoretical prediction

1 INTRODUCTION

In recent years, self-tapping screws have been widely used in timber construction, not only as connecters but also as reinforcement for various situations. Previous experimental studies have confirmed the effectiveness of self-tapping screw on improving embedment strength and tensile load-carrying capacity of dowel-type connection [1,2]. The results of the studies also showed that specimens reinforced by screws with threads on the point end achieved similar performance to connections reinforced by fully threaded screw. As the drive-in torque of a screw is related to its thread length, a fully threaded screw has higher risk of being damaged during the installation process.

In timber structures, a dowel-type moment-resisting connection is a critical part for load transfer. With weak strength perpendicular to the grain, the mechanical properties of the connection could be limited due to timber splitting parallel to the grain. Previous studies [3-5] have used self-tapping screw to reinforce bolted connections and found significant improvement on moment-resisting capacity. Currently, there is limited research on the reinforcement of moment-resisting connections, made using steel dowels, by self-tapping screws.

The aim of this study is to examine the mechanical performance of beam-to-column dowel-type connections reinforced by partially threaded self-tapping screws. A comparison with unreinforced connection is made.

2 MATERIALS AND METHODS

2.1 MATERIALS

The timber-steel-timber connections in this study are retrieved from two portal frames which were previously tested for frequency measurement without any damage. The design of the portal frame followed the guidance by Eurocode 5 (EC5 hereafter) [6].

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The connections are made of GL24c European whitewood beams which have an average density of 394 kg/m^3 (CoV= 3.7%) and moisture content (M.C.) of 7% (CoV=9.7%). In total, four beam-to-column connections were prepared and two of them were reinforced by partially threaded self-tapping screws. The steel dowel size for the connection is 16mm and the screws were placed at *1d* distance from the centre of the dowel to the centre of the screw. Figure 1 shows a drawing of the screw and its specifications.

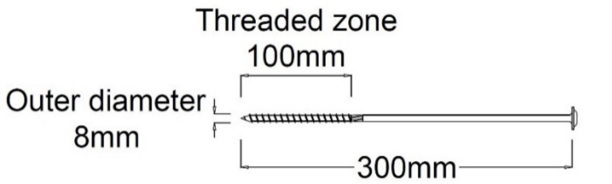

Figure 1: *The partially threaded self-tapping screw used in this study.*

Pre-drilled holes, with 180mm depth, were prepared to ensure the screws could be placed as accurately as possible. Figure 2 shows the original locations of the connections and the geometry of the connection with screw reinforcement. The original design of the portal frame left 10mm gap between the timber members. The details of the two groups are summarised in Table 1.

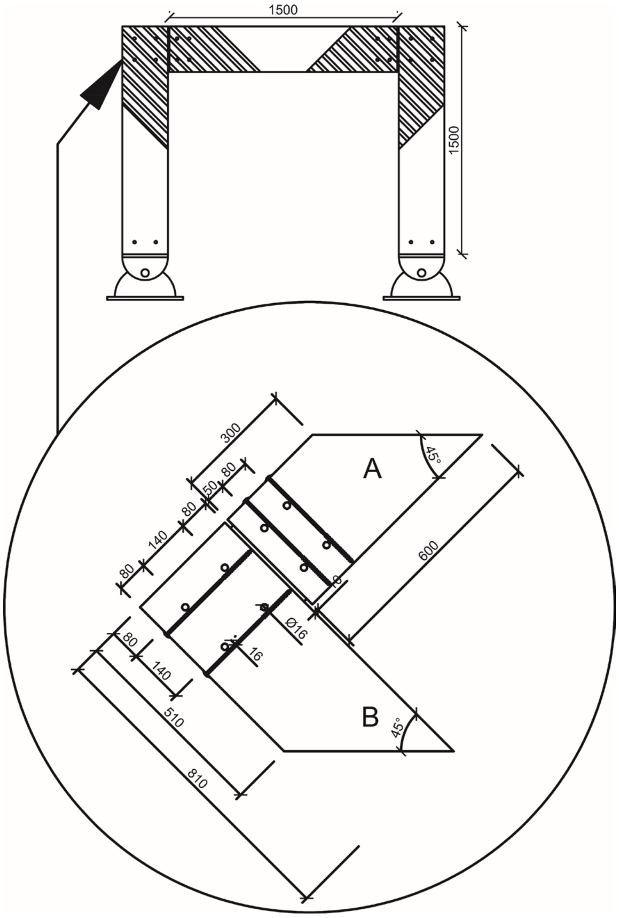

Figure 2: *Drawings of the portal frame and the shaded parts are the beam-to-column connections tested in this study*

Table 1: *Details of each group*

Group	Description	Tests	Mean density (kg/m^3) (CoV)	Mean M.C. (%) (CoV)
ULC	Unreinforced	2	393 (3.1%)	6.3 (8.5%)
RLC	Screw reinforced	2	396 (4.7%)	6.9 (9.7%)

2.2 TEST SET-UP

The beam-to-column connection was placed on a flat platform and so that the loading head above it would compress the levelled surface of part A. Two strain gauges on each side of the specimen were installed to measure the rotation of the connection, see Figure 3. The connections were loaded to failure when 20% of load drop from the peak load was observed.

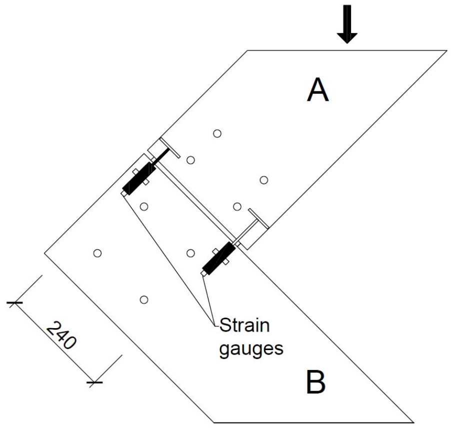

Figure 3: *Strain gauge locations for rotation measurement*

3 RESULTS AND DISCUSSION

3.1 FAILURE OF SPECIMEN

Due to the nature of the test configuration, as the part A was compressed, the 10mm gap between the two pieces gradually closed and finally the corner of part A rested onto part B as shown in Figure 4. In both tests of unreinforced and reinforced specimens, interaction between the two members was observed. This interaction shifted the centre of rotation from the centroid in part A to the bearing point for the rest of the loading stage. The location of the bearing point for each specimen was measured to be approximately 300mm from the end of part B. The observed bearing also resulted in a tensile load perpendicular to the grain of part B, which then led to the splitting of wood.

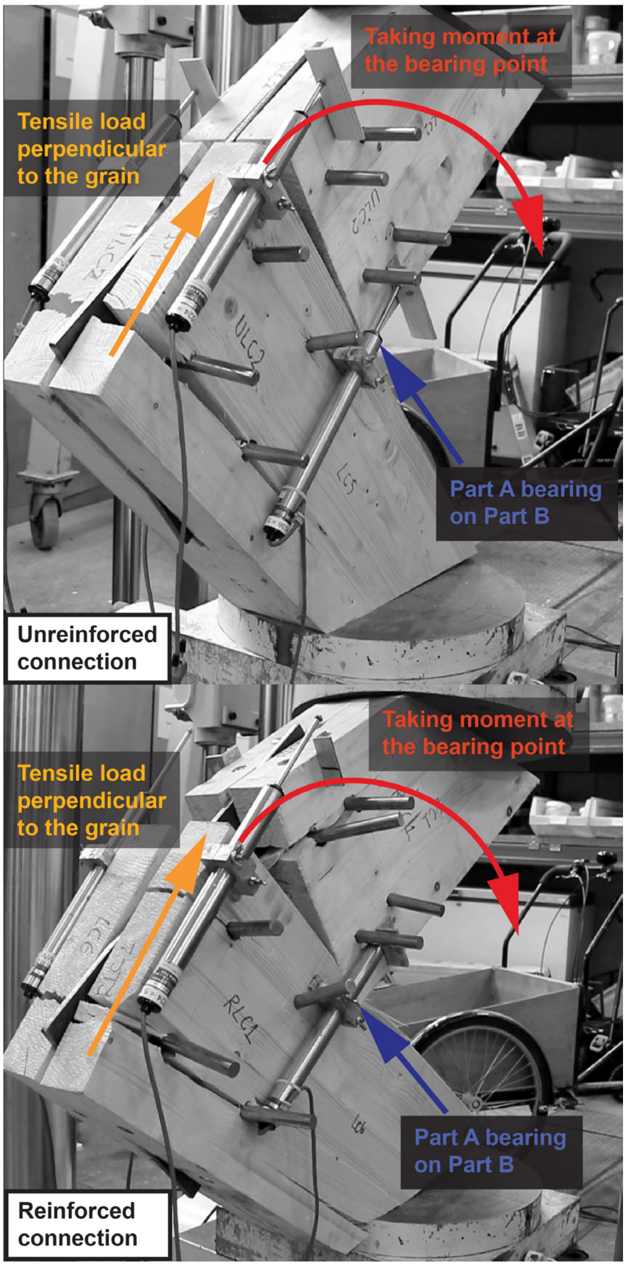

Figure 4: *Photos of unreinforced (top) and reinforced specimens (bottom)*

For the unreinforced specimens, cracks developed parallel to the grain in both parts and failed in a more brittle manner. For the reinforced specimen, as the crack develops in the member, the self-tapping screw can restrain the movement of wood perpendicular to the grain, thus, ductility of connection was enhanced. The screw head embedded into the wood as it tried to hold the timber member against splitting, see Figure 5.

Figure 5: *Embedment of screw head in reinforced connection*

3.2 LOAD-DISPLACEMENT CURVES

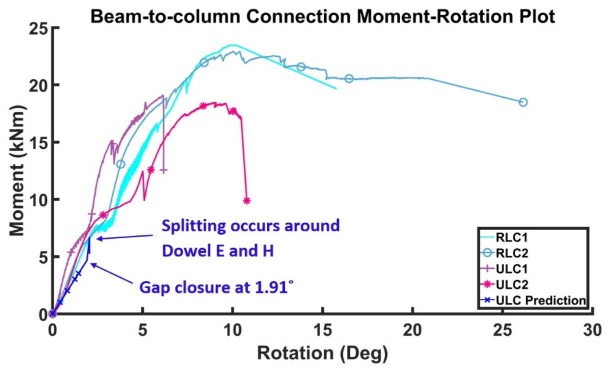

Figure 6: *Experimental moment-rotation curves and prediction for unreinforced and reinforced connections*

Table 2: *Mechanical properties of each group*

Group	Mean maximum rotation (˚) (CoV)	Mean maximum moment-resisting capacity (kNm) (CoV)	Mean stiffness (CoV)
ULC	8.50 (38.3%)	18.78 (2.4%)	17.6 (7.4%)
RLC	20.95 (34.8%)	23.20 (1.7%)	12.4 (4.1%)

For simplification, the moment on the connection is the product of the load on piece A and perpendicular distance to the bearing point, about 219mm in length. The moment-rotation curves in Figure 6 show that reinforced specimens displayed a higher rotation and moment-resisting capacity. The mechanical properties of the connections are tabulated in Table 2.

The ductility of reinforced connections is about 2.46 times better than unreinforced groups. Their maximum moment resistance is also 24% higher than the unreinforced ones. The results demonstrate that partially threaded self-tapping screws can greatly enhance the mechanical properties of beam-to-column connections. The unreinforced specimen has slightly higher stiffness than the reinforced ones. In a study [7], the analytical calculation shows that the smaller initial gap between the two timber members in a reinforced column-beam connection can have higher rotational stiffness. This is caused by the contact of the two timber members. Therefore, it is possible that the higher mean stiffness value of the unreinforced connection in this study is caused by the size of initial gap being smaller than that of the reinforced connection. The difference in initial gap could be due to errors when manufacturing the members or during assembling the connection.

3.3 THEORETICAL PREDICTION OF MOMENT-RESISTING CAPACITY

Current design codes have no relevant methods for prediction of the moment-resisting capacity of screw reinforced dowel-type connections.

A preliminary calculation method is constructed based on the design of semi-rigid connection and using the embedment strength acquired from tests in previous work [1,2]. The proposed method split the loading stage of the connection into two substages. The initial stage assumes each fastener group in Part A and B rotates around the centre of rotation, respectively. The second stage assumes, after the gap is closed, Part 1 continues to bear on Part 2 and rotate around the bearing point which has become the centre of rotation of the fastener in both parts. During the tests, a crack first appeared around dowel E in all specimens. This is due to excessive tensile stresses perpendicular to the grain caused splitting failure of the connection. Therefore, using the splitting capacity of the connection provides a path to calculate the moment-resisting capacity of the connection for the second stage.

Based on the preliminary calculation method, the peak moment-resisting capacity of the unreinforced connection before splitting failure is 6.69kNm.

During the tests, splitting occurs at dowel E and almost simultaneously propagates to the wood around dowel H as shown in Figure 7. To reflect the test results, this study assumes dowels with surrounding splitting do not contribute to the rotational stiffness of the connection. Calculations show that after splitting occurs to dowel E and dowel H the characteristic moment-resisting capacity of the connection drops to 5.29kNm, about 20% capacity drop, meaning the connection fails.

A predicted moment-rotation curve for the unreinforced connection is shown in Figure 6. The prediction shows conservative value compared to actual test results. Moreover, it reflects the splitting failure of wood around dowels E and H when Part A starts to bear on Part B.

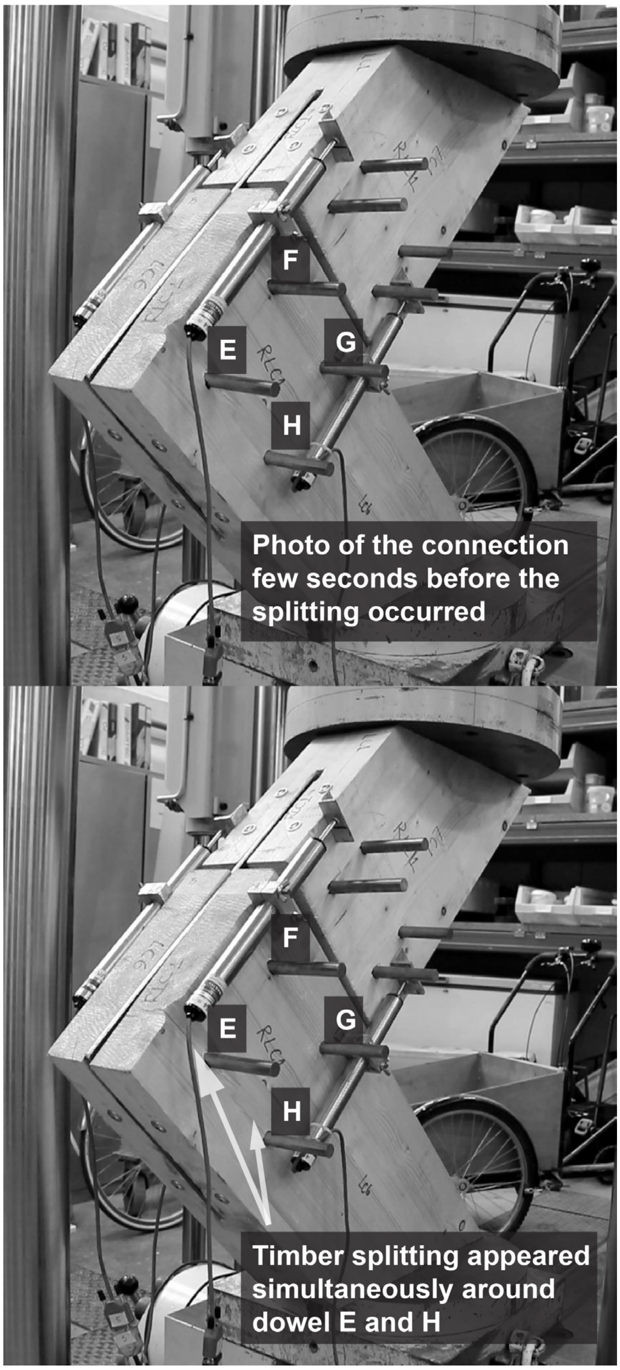

Figure 7: *Photo of the reinforced connection (RLC1) before splitting occurred (top) and a few seconds later the splitting of wood around dowel E and H (bottom)*

Unfortunately, as the bearing behaviour of the connection shifted the rotation centre to the bearing point, the dowels tend to move away from the self-tapping screws rather than moving towards them. Thus, the dowels in the tests did not bear on the self-tapping screws as observed in previous work [1,2]. The proposed prediction method therefore cannot predict the moment-resisting capacity of the reinforced connection using the embedment strength of screw reinforced timber.

However, self-tapping screws can provide restraint to splitting and the tested reinforced connections showed higher ductility and moment-resisting capacity than unreinforced ones. The splitting resistance provided by the screws effectively controlled crack propagation and allowed the yielding of fasteners thus higher mechanical performance of the connection can be achieved.

3.4 SCREW REINFORCEMENT DESIGN

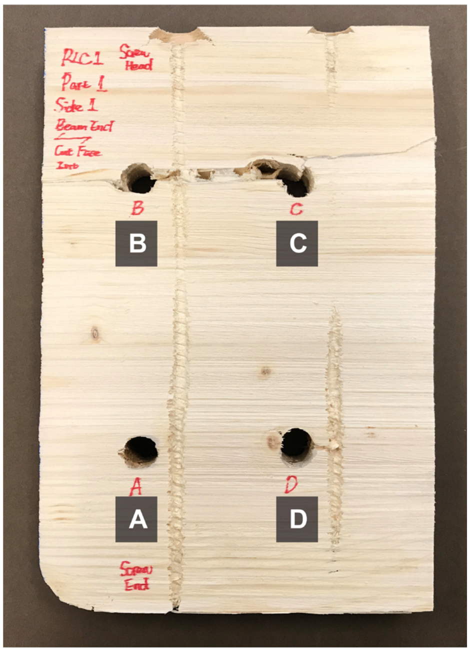

Figure 8: *Image of the cut piece of Part 1 from reinforced connection (RLC1)*

The purpose of screw reinforcement in this study is to provide splitting resistance and enhance the capacity of the connection when the steel dowels bear on the screws. However, as stated in the previous section, the centre of rotation is shifted to the bearing point making it impossible for the dowels to bear on the self-tapping screws. After the test, the reinforced connections were dismantled and cut for inspection. In Figure 8, none of the dowels in Part A showed the movement to bear on the self-tapping screws. As for the dowels F and G in Part 2 in Figure 9, they showed a tendency to move towards the self-tapping screws but, overall, the deformation of the screws was insignificant in both parts, see Figure 10 and 11. The self-tapping screws in this study did not provide the extra enhancement on the embedment strength using their bending capacity. However, the deformation of a few screws due to the splitting failure and the embedment of screw head indicated restraining resistance was provided by the screws.

The results of this study provide insights on the effective positioning of the self-tapping screws regarding the design of the connection. Installing the screws at the locations where the dowels can rest on the screw may result in a higher capacity and ductility of the connection. Besides, the self-tapping screws were placed at *1d* distance to the dowels and decreasing this spacing may utilise the bending capacity of the screw and further enhance the moment-resisting capacity of the connection.

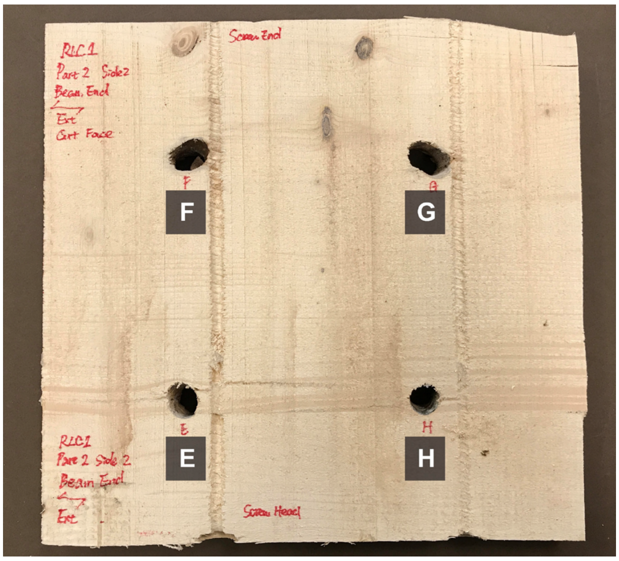

Figure 9: *Image of the cut piece of Part 2 from reinforced connection (RLC1)*

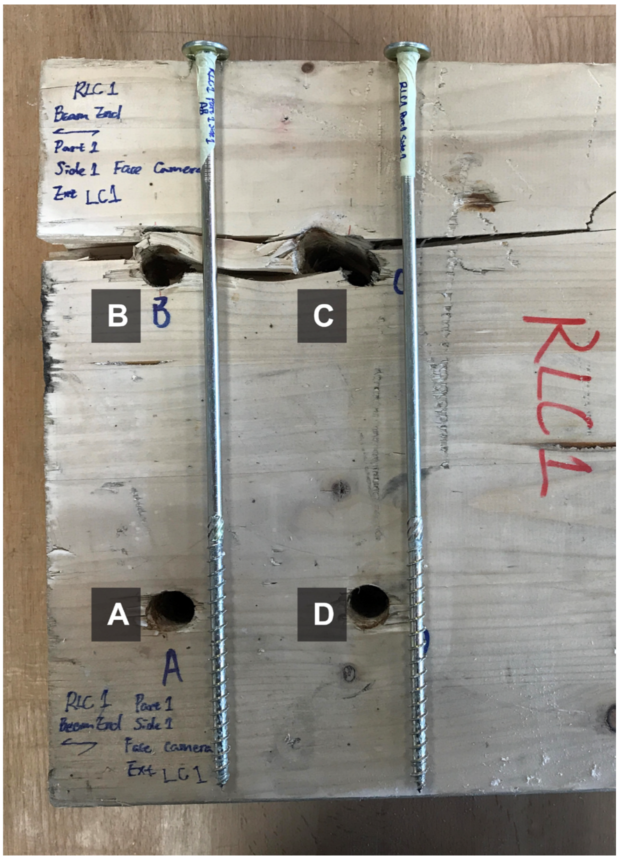

Figure 10: *Image of the screws retrieved from Part 1 of the reinforced connection (RLC1)*

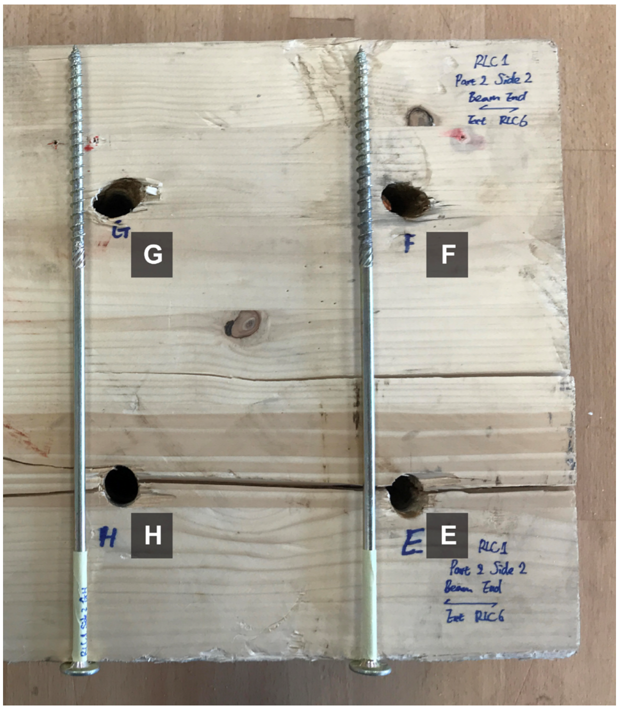

Figure 11: *Image of the screws retrieved from Part 2 of the reinforced connection (RLC1)*

4 CONCLUSIONS

In this study, a total of four beam-to-column dowel-type connections were tested. The mechanical properties between unreinforced and reinforced connections are compared and the following points can be concluded:

- Self-tapping screws can significantly improve the moment-resisting capacity and ductility of beam-to-column connections. The variation in stiffness could be a result of the difference of the initial gap between the two timber members during manufacture. A larger gap can reduce the rotational stiffness.

- A preliminary calculation method of moment-resisting capacity of unreinforced connections is presented. The moment-rotation curve produced by this method reflects the behaviour of the connection when the gap gradually closes and the two timber members start bearing on each other, leading to excessive tensile stresses perpendicular to the grain and finally splitting failure. The predicted moment-resisting capacity of the unreinforced connection shows a conservative value compared to test results.

- The bearing behaviour shifted the centre of rotation in each fastener group to the bearing point causing the dowels tend to move away from the self-tapping screws. Consequently, the dowels did not bear on the self-tapping screws that were observed in embedment tests in previous work. Thus, the moment-resisting capacity of the reinforced connection is not predicted in this study.

- This study considers the location of the self-tapping screws is essential to utilise the mechanical properties of the screw as reinforcement. And the design of the connection, such as the size of the gap between the two parts in this study, can have a critical impact on determining the location of the screw.

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